Circuit board and method for embedding an optical component in a circuit board

The present invention relates to a method, according to the preamble of claim 1, for embedding an optically active component in a circuit board. The invention also relates to a circuit board according to the preamble of claim 13.

Publications according to the prior art, for example, patent application publication US 2002/0141163 disclose solutions, in which an opto-electric component is embedded inside a circuit board. In these solutions, a mirror is used to guide an optical signal along an optical bus to the component. The problem in these solutions is their low efficiency, because the inversion of the optical signal attenuates the intensity of the light. The typical loss can be about 50 %.

In some publications according to the prior art, the optical signal is led along an optical bus without a mirror. For example, patent publication EP 1376180 discloses the embedding of a light-receiving and transmitting module in a circuit board, in such a way that the modules come into contact with an optical bus located between them. The light receiving and transmitting module is electrically connected to the wiring pattern. A corresponding solution is also disclosed in patent publication US 5,521,992. Patent publication US 6,477,286 discloses a solution, in which the component is embedded in the circuit board and attached to its base with the aid of solder balls. Patent publication US 4,732,446 discloses a solution, in which the carrier of the component is embedded in a circuit board, which is connected between two other circuit boards.

The invention is intended to create a new type of method for embedding optically active components inside a circuit board.

The invention is based on the idea that the component, the top and/or surface of which is optically active, is embedded either partly or entirely inside a circuit board, in such a way that the optically active area of the component comes into the vicinity of the end of the optical bus and that the surface of the optically active area takes up a position that is essentially at right angles to the plane of the circuit board.

More specifically, the method according to the invention is characterized by what is stated in the characterizing part of claim 1.

The construction according to the invention is, in turn, characterized by what is stated in the characterizing part of claim 13.

In a construction according to a preferred embodiment of the invention, there is an optically active area and an area or areas containing conductive material on the first side of the component. When the component is embedded, the optically active area is placed in the vicinity of the end of the optical bus, in such a way that the optically active area of the component lies at essentially right angles to the plane of the circuit board. The optically active area can be, for example, a flat or curved surface, which transmits or receives light. The active area can also be a surface constructed from several sub-components. The surface of the active area of the component, surface of the sub-component, which transmits or receives light, is preferably place at right angles to the plane of the circuit board. The optical signal is thus directed straight at the surface of the active area of the component, or from the surface to the optical bus, so that the signal need not be deflected. This avoids the weakening of the optical signal that occurs when it is reflected through a mirror.

The electrical connection to the conductive layers of the circuit board can be made through areas in the component that contain conductive material. The conductive material can be, for example, on the same side of the component as the optically active area, and on the opposite side, or on the adjacent side.

Considerable advantages are gained with the aid of the invention. In previous solutions, the inversion of the optical signal away from the plane of the board causes a considerable loss of intensity in the signal. The loss due to the inversion of the optical signal is typically about 50 %. If, for example, the optical path from the transmitter to the receiver includes two optical inversions, 75 % of the intensity of the signal will be lost simply due to losses arising from the inversion of the signal.

The invention has many preferred embodiments. With the aid of the invention, it is possible to embed electro-optical components, such as detectors and light-emitting components, with a good efficiency. It is preferable to embed an active photo-component, particularly a

component that transmits or detects light from its top surface, on top of, and/or on the surface of the circuit board. Such a component comprises on one side both an optically active area and at least one conductive area. It is considerably cheaper to manufacture such a component than a photo-component that emits or detects light from the side, the manufacture of which demands special technology.

In the following, the invention is examined in greater detail with the aid of examples of applications and with reference to the accompanying drawings. The examples of applications are in no way intended to restrict the scope of protection defined by the claims.

Figure 1 shows a cross-section of one circuit board according to the invention, at the feed-through for a component.

Figure 2 shows a cross-section of the recess drilled in the circuit board.

Figure 3 shows a cross-section of the component being attached in place in the recess.

Figure 4 shows a cross-section of the infilling of the recess remaining around the component.

Figure 5 shows a cross-section of the connection of the component to the conductor layers of the circuit board.

In connection with the present invention, the term 'circuit board' refers to a multi-layer circuit board, in which there are at least two conductor layers, which are typically patterned, electrically conductive signal layers. Patterning refers to the fact that the conductor layer is not uniform, but is formed of conductor patterns, which are formed of conductors that are electrically insulated from each other. The conductors are of some electrically conductive materials, typically metal, and usually copper. The conductor layers are separated from each other by an insulating layer. At least one of the circuit board's conductor or insulation layers includes an optical bus.

The term 'optical bus' refers to a channel, along which it is possible to lead an optical signal to

a component, or away from a component. The optical bus can be filled with a suitable substance, which forms a path for light. Suitable substances for filling are, for example, various polymers, or glasslike materials.

The construction of an optical bus is disclosed in, for example, patent application publication US 2003/0006068.

The circuit board structure, in which the opto-electronic component is at least partly embedded, is preferably one in which there is only insulating material at the embedding location of the component. Thus a recess can be made to the desired embedding depth at the embedding location of the component, using a laser drilling method, or other similar drilling method, which terminates at the metal layer. It is also possible to use several methods, for example, in such a way that an initial recess is first made by mechanical machining, and is then finished by the laser drilling method.

The recess for the component is made in such a way that it intersects the optical bus in the circuit board. The term intersecting refers to the fact that a common interface is formed between the recess and the optical bus, through which a signal progressing along the optical bus transfers from the optical bus to the recess, or correspondingly an optical signal transfers from the recess to progress along the optical bus. In this document, such an interface is referred to as an intersection surface. The intersection surface preferably completely breaks the optical bus and is preferably at essentially right angles to the direction of movement along the optical bus. In an advantageous case, the intersection surface essentially corresponds to the cross-section of the optical bus at the end of the optical bus. The actual intersection surface can be manufactured using any suitable method whatever, but in terms of manufacturing technique it is easiest to manufacture the intersection surface in such a way that, in making it, the material of the optical bus is removed at the end of the bus. In several embodiments this removal of the material is performed in connection with the making of the recess.

When the component is embedded in the recess, the empty space remaining around it is filled partly or entirely using some suitable insulating material. The recess between the optically

active area of the component and the end of the optical bus is filled with a transparent insulating material, preferably the same material as the optical bus contains. The empty space in the other directions around the component can be filled partly or entirely with the same or some other insulating material. In terms of the manufacture of the circuit board, it is simpler, if the insulating material is the same transparent material as that in the optical bus. In some embodiments, at least part of the recess can be left unfilled.

The component is placed in the recess in such a way that the optically active area of the component comes into the vicinity of the intersection surface of the optical bus. In this case, the concept 'into the vicinity' is intended to also cover the special case, in which the intersection surface of the optical bus touches the optically active area of the component. Operationally, the concept 'into the vicinity' refers to a distance and position that permit a sufficiently effective transfer of a signal progressing along the optical bus from the optical bus to the intersection surface and through a possible medium to the active area of the component, or vice versa. In practical embodiments, the distance between the surface of the optically active area and the intersection surface of the optical bus is typically in the range 0 - 2 millimetres and preferably in the range 100 - 500 micrometers.

The component can comprise electrically conductive material on one or more sides of the component, in order to form an electrical contact. The component can be connected electrically to the conductor layers at different heights in the circuit board. The connection can be made, for example, to a conductor layer on the first surface of the circuit board and to a conductor layer on the second surface of the circuit board. In this case, the first surface of the circuit board refers to the component embedding side and the second surface to the surface on the opposite side of the circuit board. The component can, of course, be also connected to one or more conductor layers inside the circuit board, in addition to or instead of a conductor layer of the surface of the circuit board.

The connection to the conductor layer of the first surface of the circuit board can be made in such a way that the recess between the component and the circuit board is not entirely filled with insulating material, but instead the upper part is filled with a conductive material, through which the conductive material of the component can be connected to the conductive layer on

the surface of the circuit board. Alternatively, the insulating material can be removed from the recess between the embedding location of the component and the circuit board and replaced with a conductive material. The conductive material preferably does not extend to a point on the optical bus at which it could interfere with the travel of the optical signal. If necessary, the conductive material can extend right to the bottom of the recess, if the conductive material does not interfere with the progress of the optical signal.

The conductive material of the component can be connected to the conductor layer on the first surface of the circuit board through several connections, or some of the connections can be made to the conductor layer of the first surface of the circuit board and some connections to the conductor layer of the second surface of the circuit board. In the manufacturing stage of the circuit board, a continuous or discontinuous metal layer can be left at the embedding depth beneath the component, the metal layer being preferably of the same material as the conductor layer at the same height. The component can be attached to this metal layer with the aid of a conductive adhesive, solder, or a conductive polymer, if the other connection is made through the underside of the component. The metal layer under the component can, in turn, be connected to the conductor layer located on the undersurface of the circuit board, using some suitable feed-through method, such as the micro-via method. Alternatively, the component can be attached to the metal layer with the aid of an insulating adhesive, if all of the connections are made through the upper side of the component. According to a preferred embodiment, a photo-component with an active top surface, which is placed in the side of the circuit board, is connected to the metal layer underneath with the aid of a conductive adhesive.

The connections, or some of the connections can be made to a conductor layer located on the surface of, or inside the circuit board also, for example, with the aid of bonding (for example, wire-bonding with the aid of gold or aluminium wire, or a conductive adhesive).

The 'component' is typically an opto-electronic component, for example, a detector or a light-emitting component. The component can thus be equally well transmitting as receiving. The component is preferably a photo-component that is active on top and/or on the surface, particularly a component that emits or detects light from its top surface. A component that emits or detects light from its top surface is preferably a component, in which on the same

side there is an area containing conductive material, i.e. an electrical contact, such as an anode contact, as well as an optically active area. A second area containing conductive material, i.e. an electrical contact, such as a cathode contact, can be located on the same side of the component as the optically active area, or on the opposite side of the component. When the component is set in place on the side of the circuit board, the surface of its optically active area and also the electrical anode and cathode contacts (pads) lie at right angles to the surface of the circuit board. Examples of active photo-components are a photodiode, a photo laser, and an LED.

The component can be embedded partly or entirely inside the circuit board and it can be attached to either of the sides of the circuit board.

The term 'active area' of an optical component refers to a surface of the optical component, which transmits and/or receives light, in order to achieve a desired function. The active area of semiconductor components can, for example, convert electrical energy into light energy, or vice versa. The light being received can also, for example, release a charge carrier in the active area, so that the conductivity of the component changes. The term active area can also refer to the surface of a component constructed from several sub-components, which transmits or receives light. A light transmitting or receiving semiconductor, such as a semiconductor laser, LED, or photodiode, for example, comprises the function of an active area.

How many conductor layers are enabled depends on the application. At least one of the semiconductor layers can represent 0, i.e. the ground reference plane, which is grounded or connected to some other 0-potential, for example, to the 0-potential of the circuit.

If necessary, the component can be protected, for example, with the aid of an electrically conductive sticker, from above the component, i.e. from the embedding side of the component.

Around the embedded component, there can also be a layer protecting against electromagnetic radiation coming from the direction of the circuit board, i.e. a so-called EMI shield. A preferred construction is disclosed, for example, in the as yet unpublished patent application

FI 20031796. In order to construct an EMI shield, a recess is made in the circuit board around the embedding location of the component and the recess is surfaced or filled with an electrically conductive material, in such a way that the surfaced or filled recess forms a bezel around the component, which protects the component from electromagnetic radiation coming at least from the lateral direction of the circuit board. An insulating layer, which insulates the component and the bezel from each other, is preferably left between the bezel that is formed and the embedding opening for the component. In the case of the present invention, the shielding bezel must not be unbroken; instead an opening should be left at the location of the optical bus. In addition, the material at the opening should be transparent, so that an optical signal can travel through the material from the optical bus to the component, or from the component to the optical bus. The term 'transparent' should be understood to be relative to the wavelength used, i.e. the transparent material permits the easy passage of the wavelength used, but may be opaque to other wavelengths. In terms of the application, the transparent material can thus, for example, permit the passage of light at infrared wavelengths, but not permit passage at wavelengths that are visible to the human eye.

Possible materials for the optical bus are, for example, siloxane polymers, acrylates, polyimides, olefines, SU-8, Sol-gel, ORMOCER (ORganically MOdified CERamics), PMGITM, and Ultem.

The insulating material between the conductive layers of the circuit board can be plastic or epoxy or some similar material. The insulating material is a material that does not act as an electrical transfer path. The insulating material can be selected, for example, from the group: various resins, epoxy glass, polyimide (e.g. Dupont KAPTON), polyimide-quartz, polyester, acryl, bismalemide, triatsine, glass-fibre, cyanate-ester glass, XPC (paper phenol), FR-1 (paper material, containing a phenolic binder), FR-2 (paper material, containing a phenolic binder UL94-V0), FR-3 (paper material, containing epoxy resin), FR-4 (glass-fibre epoxy laminate), CEM (composite epoxy material), CEM-1 (paper-based laminate, in which there is one layer (7628) of woven glass-fibre), CEM-3 (glass epoxy), aromatic polyamide (aramide fibre, e.g., Dupont's Kevlar, Epoxy-Kevlar, or Nobel's Twaron), PTFE (Teflon), benzocyclobutene, microfibre laminate, and Bakelite.

Special bases can be aluminium to in general, LTCC (low-temperature co-fired ceramics), HTCC (high-temperature co-fired ceramics), glass, quartz/silicon dioxide, AlN, SiC, silicon, BeO, and BN.

Plastics, which can be used as the insulating material in the circuit board, that can be referred to include: polyethene, polypropene, polybutene, polymethylpentene, polyamides, polyimide, polysulphone, polyether ether ketone (e.g. PALAP, developed by Denso Corp. and Mitsubishi Plastics, Inc.), polyvinylchloride, styrene plastics, cellulose plastics, polymethylmetacrylate (PMMA), polyacrylnitrile, polycarbonate, polyetheneterephtalate, and fluor plastics.

Electrically conductive polymers and adhesives can be divided into thermosetting polymers and thermoplastic polymers. In order to increase conductivity, a filler, e.g., silver, gold, or nickel, can be used.

Conductive polymers are, for example, polyacetylene, polytiophene, polypyrrole, poly(p-phenylenevinylene, polyaniline, poly/2,3-ethyldioxitophene).

A conductive adhesive usually consists of three main components: a conductive filler, a polymer, e.g., epoxy, modified epoxy, or silicone, and, for example, an additive/agent that provides an antistatic property. Curing/drying takes place using UV light, or heat, depending on the adhesive used. Certain adhesives will dry already at room temperature.

Commercial (one or two-component) electrically conductive isotropic adhesives include:

Emerson & Cumming
Ablebond 976-1, flexible, electrically conductive adhesive, filler silver
Ablebond 84-ILMI NB, electrically conductive epoxy adhesive, filler silver
Eccobond 57 C, electrically conductive epoxy adhesive, filler silver
Eccobond 50298, two-component, electrically conductive epoxy adhesive, filler silver
AMICON C 850-6 epoxy adhesive, filler silver
AMICON CE 8500, electrically conductive, modified epoxy adhesive, filler silver

Northrop Grumman Corporation

SE-SECURE 9502, electrically conductive adhesive, filler silver

Loctite

Product 3880, electrically conductive epoxy adhesive, filler silver (particularly for attaching EMI components)

Product 3888, epoxy adhesive, filler silver

Product 5420, electrically conductive silicone

Product 5421 RTV, silicone (provides EMI/RFI shielding)

Dow Corning

DA 6524, electrically conductive silicon adhesive

DA 6533, electrically and thermally conductive silicone adhesive

Panacol-Elosol Gmbh

Elecolit 312 LV, solvent-free epoxy adhesive, filler silver

Elecolit 323, conductive epoxy adhesive, filler silver

Elecolit 342, conductive acrylate adhesive, filler silver

Elecolit X-160378, conductive epoxy adhesive, filler silver

Commercial (one or two-component) electrically conductive anisotropic adhesives include:

Loctite

Product 3441, epoxy adhesive, gold-surfaced polymer

Product 3446, epoxy adhesive, fusible filler

Product 3440, gold-polymer filler

Product 3445, fusible solder filler

Telephus

AcpMat series, epoxy-based adhesive resin paste, which contains a conductive filler and other special filler agents

Figure 1 shows a cross-section of one basic construction of the circuit board. In connection with the manufacture of the circuit board, alternating conductive layers 1 and insulating layers 2 are constructed in the circuit board. In addition, an optical bus runs inside the circuit board, along which optical signals can be transmitted to the components, or away from the components. In the circuit board of this example, there are at least two conductor layers: one conductor layer above the bus and one conductor layer below the bus. Typically, there are 2 - 4 conductor layers on top of, or beneath the optical layer. The optical layer can be located, not only in the position of a conductor layer, but also of an insulating layer. In addition, it is possible for one of the conductive layers to correspond to the ground reference level, i.e. the 0-level.

In order to allow the components to be embedded more easily inside the circuit board, in the manufacturing stage of the circuit board an area, which at least on one side, i.e. the side facing the component embedding location, is free of the conductive layers and thus contains only insulating material, is constructed at the component embedding location. In the embodiment that is shown in Figure 1, an opening is left in the conductor layer 1 at the embedding depth at the component embedding location. In the manufacturing stage of the circuit board, a continuous or discontinuous metal layer 5, which is formed of the material, for example copper, of the conductor layer 1 at the same level, can be left in this opening. Insulating material 2 is left in the openings.

If it is wished to bring the component into electrical contact with the conductor layer 1 below the component embedding location, it is best to make a feed-through 6 prior to the manufacture of the metal layer 5, using some suitable feed-through method, for example, the micro-via method, through the insulating layer 2 at the component embedding location to the conductor layer situated below. The feed-through 6 is of some electrically conductive material, such as a metal.

Figure 2 shows a cross-section of the recess 4 drilled in the circuit board of Figure 1. A recess 4, extending to the conductor layer located at the embedding depth below the component embedding location, is cut into the circuit board at the component embedding location, using a selective laser drill or a similar method. The conductor layer should preferably be beneath

the entire area in which the drilling is carried out, to facilitate the depth control of the drilling. There is preferably no conductor layer 1 in the cutting zone, so that depth control can take place with the aid of the metallic conductor layer. For example, selective laser drilling does not eat metal, but only the insulating layer, so that cutting will stop when it reaches the conductor layer 1.

Figure 3 shows a cross-section of the component 8 being embedded in place in the side of the circuit board of Figures 1 and 2. In the embodiment of Figure 3, there is conductive material 10 and 12 on two separate sides of the component, through which the component can be connected to the conductor layers situated at different heights in the circuit board, for example, to the conductor layers 1 situated at the first and second surfaces of the circuit board. One side of the component comprises an optically active area 11. The component is embedded in place in such a way that the surface of the optically active area lies at essentially right angles to the direction of travel of the optical signal and thus also to the place of the circuit board. In the embodiment of Figure 3, the optically active area 11 and the area 12 containing conductive material are on the same side of the component and the second area containing conductive material 10 is on the opposite side. One of the areas of conductive material can also be on the side adjacent to the optically active area.

The component 8 is attached to its contact base, for example, using isotropically or anisotropically conductive adhesive 7, or by soldering, or using a conductive polymer with a sufficiently high conductivity. In the embodiment of Figure 3, the component is attached to the metal layer 5 with the aid of a conductive adhesive 7. The electrical connection to the conductive conductor layer 1 situated below the component 8 can be implemented using some feed-through method through the insulating layer 2, for example, the micro-via method (micro-via 5). The conductor layer 1 below the component 8 can also be constructed only after the electrical connections have been made through the insulating layer 2 beneath the component 8 embedding location. Alternatively, the conductor layer 1 beneath the component 8 embedding location can be ready and the connections made through it.

The components can also be attached to the base with the aid of a non-conductive adhesive, if all the connections are made from above the component, using a conductive adhesive, wire-

bonding, or some other suitable method.

Figure 4 shows a cross-section of the component 8 embedded in place in the circuit board of Figures 1 and 2. After the embedding of the component 8, the recess 4 remaining around the component is filled partly or entirely with some suitable insulating material 9. The essential factor is that the insulating material fills at least the area between the optically active area 11 of the component and the optical bus and that at least at this point the insulating material is transparent. The insulating material 9 is preferably the same material as the material in the optical bus 3. The insulating material 9 on the other sides too of the component 8 is preferably the same material and the insulating material in the optical bus 3.

Figure 5 shows a cross-section of the component 8 embedded in place in the circuit board of Figures 1 and 2 and connected to the conductor layers at different heights in the circuit board, for example, to the conductor layer 1 on the first surface of the circuit board, or to the conductor layer on the second side, or to both. The layer 12 of conductive material on the first surface of the component can be connected to the conductor layer 1 on the first surface of the circuit board, in such a way that a pit, which is filled with a conductive material 13, such as a conductive adhesive or polymer, is constructed in the upper part of the recess 4 between the component 8 and the circuit board. If the recess 4 between the component 8 and the circuit board is entirely filled with insulating material, the insulating material should be removed and replaced with conductive material 13. Alternatively, the recess 4 is filled to only above the optical bus 3 and the upper part of the recess is filled with a conductive material. An electrical contact can be formed between the layer 12 of conductive material on the first side of the component and the conductor layer 1 of the first surface of the circuit board, by means of an area of conductive material 13 in the upper part of the recess 3 between the component and the circuit board.

An electrical connection can also be made through the conductive material 10 located at the second side of the component, to the conductor layer 1 located on the second surface of the circuit board. The electrical contact can be formed through conductive adhesive 7 at the attachment point of the component, solder, or a polymer, through the metal layer 5 located beneath the component embedding location, to the conductor layer 1 located beneath the

component, by a micro-via 6.

Alternatively, the connections, or part of the connection can be made to the conductor layer located on the first or second surface of the circuit board, for example, with the aid of bonding (for example, wire-bonding using gold or aluminium wire).

If necessary, the component can be protected from above the component, i.e. from the opposite side to the component's attachment point, for example, with the aid of an electrically conductive sticker.